The Study of Venus' Interior using Balloons in its Atmosphere

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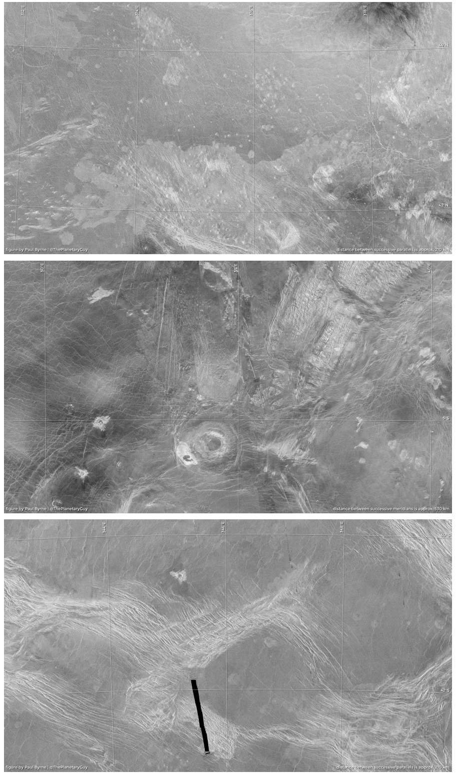
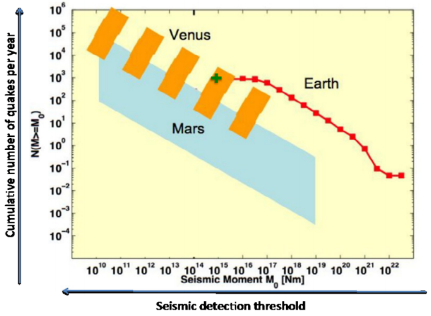
Venus Interior and Seismicity

- Venus is similar in mass and volume to Earth
- The surface of the planet has its own distinctive tectonic and volcanic character
- Estimates of Venus seismicity vary over a large range – no direct or indirect measurements available
- Detection of seismic activity can establish if tectonism is still active and can be used to probe the crust and interior of the planet
- Surface conditions are harsh, spacecraft lifetime is limited

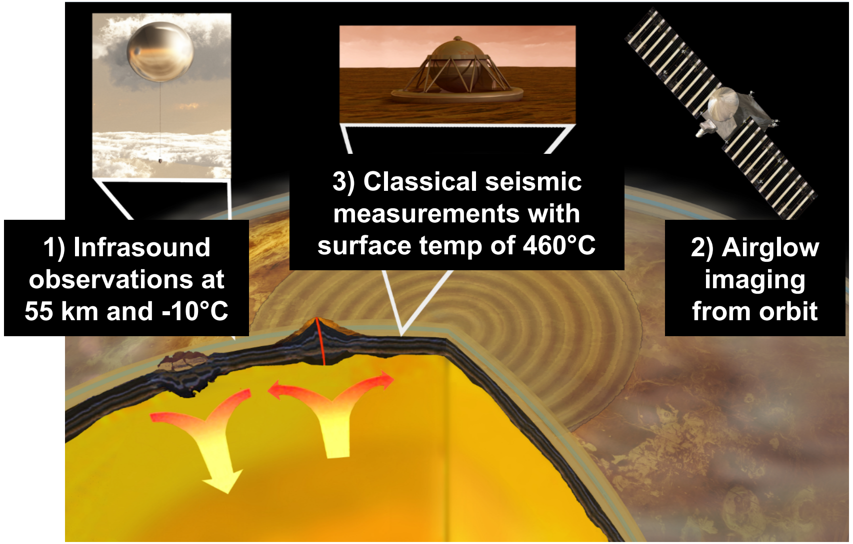


Byrne, 2018



Lognonne and Johnson, 2005

Options for Seismology on Venus

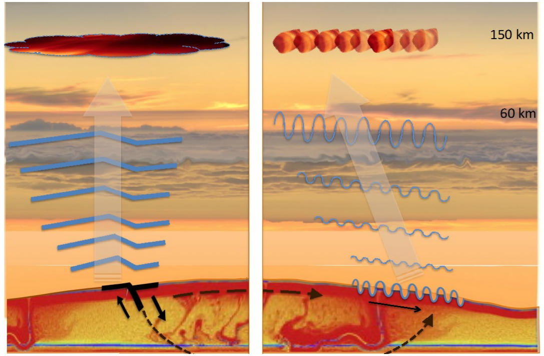


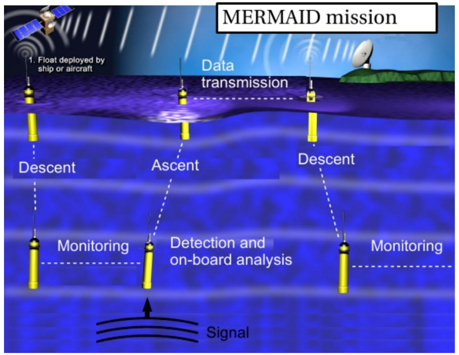
Cutts et al. (2015)

- Surface conditions are harsh – 460◦C, 90 atmosphere, sulfuric acid-rich environment, precluding long-term observations with sophisticated seismic sensors
- Infrasound observations from floating platforms in the middle atmosphere and from orbit are practical alternatives

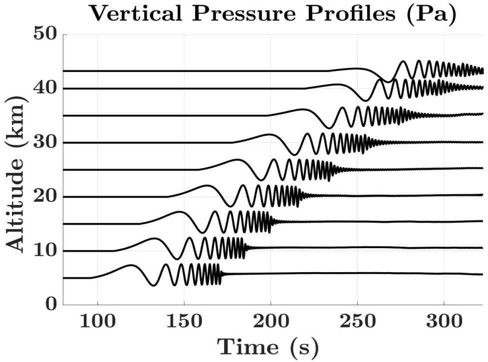
Infrasonic Remote Sensing on Venus

- Energy from ground motion couples to the atmosphere-thermosphere-ionosphere system
- Seismo-acoustic coupling is 60x better on Venus than the Earth
- Acoustic waves may be detected by barometers at 60 km altitude (~ 0 C and 1 atm)
- Acoustic waves interact with the “airglow layer”, which can be imaged from orbit



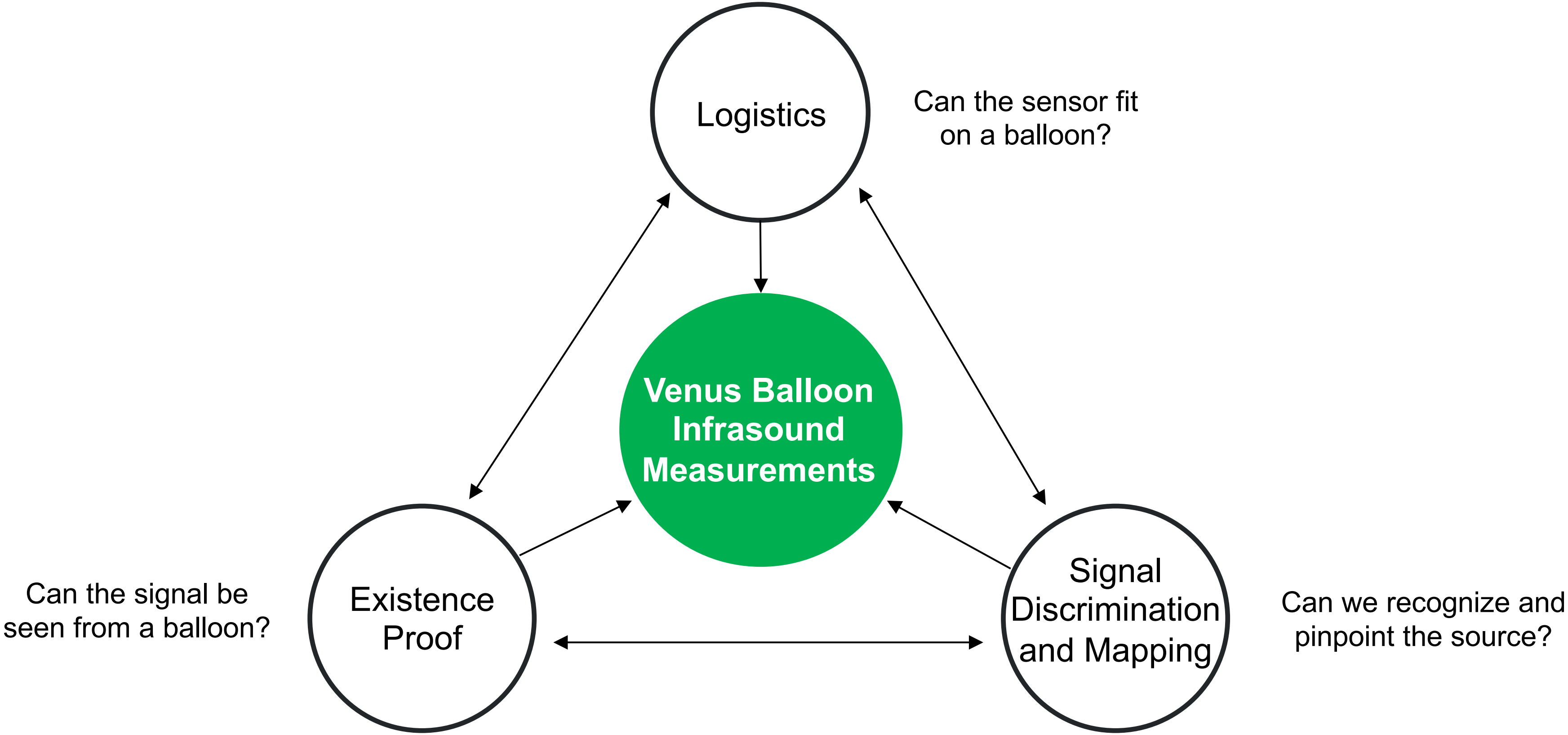


MERMAID Mission/Alex Sukhovich/www.argo.ucsd.edu (2019)



Garcia et al. (2016)

Balloon-Based Seismology on Venus



Balloon-Based Seismology on Venus

Existence Proof

Short-range seismic infrasound detection using weak seismic sources (Seismic Hammer)

Medium-range seismic infrasound detection using subsurface explosions

Long-range seismic infrasound detection and characterization using natural quakes

Signal Discrimination and Mapping

Studies of infrasound background on Earth and mapping to Venus

Signal modeling (generation and propagation)

Signal collection and classification

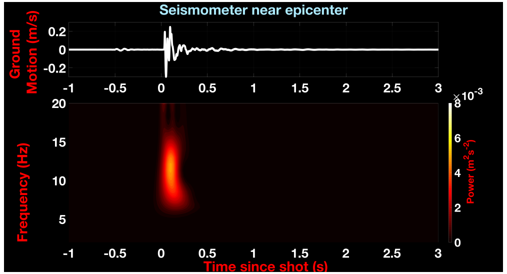
Signal geolocation

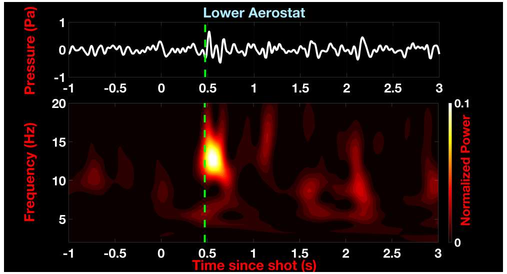
Logistics

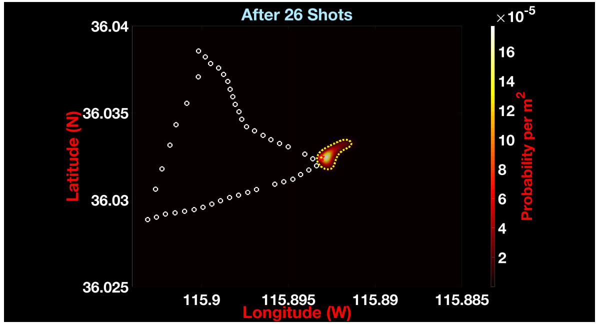
Sensor miniaturization (mass, power, deployment)

Automated signal detection and classification (low data budget)

Artificial Earthquake Detection from Balloons







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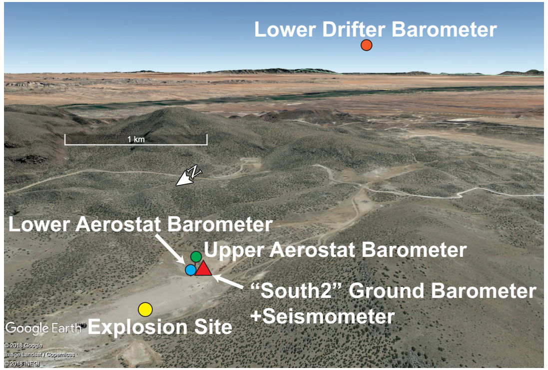
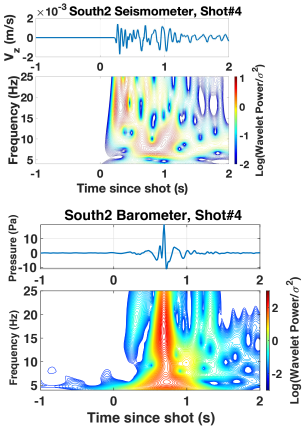
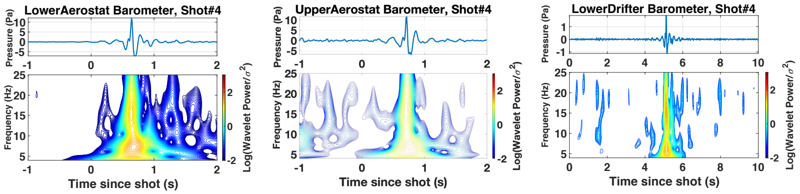
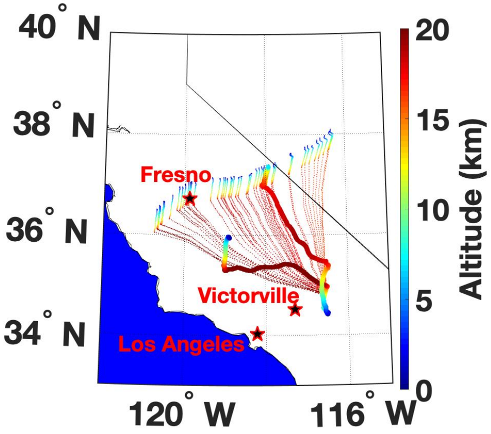
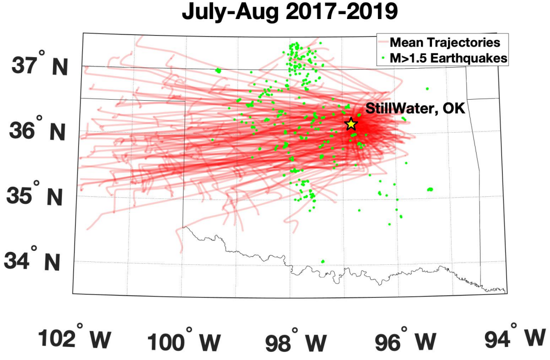


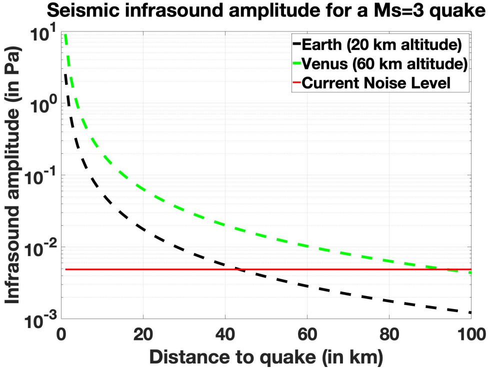




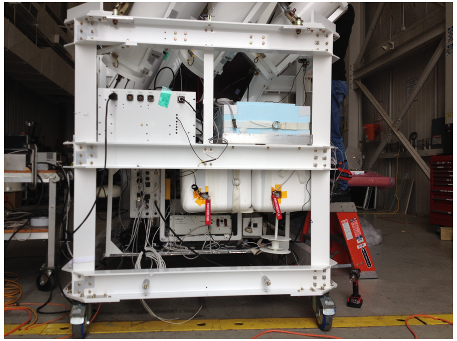
Natural Earthquake Detection from Balloons

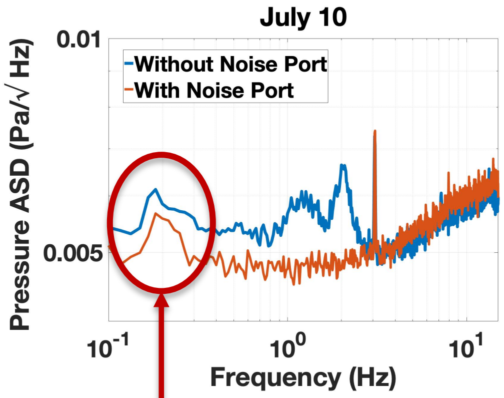




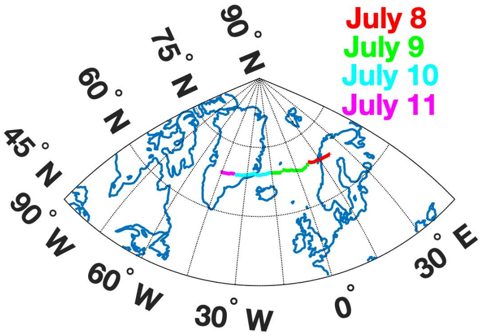


Data Collection Flights

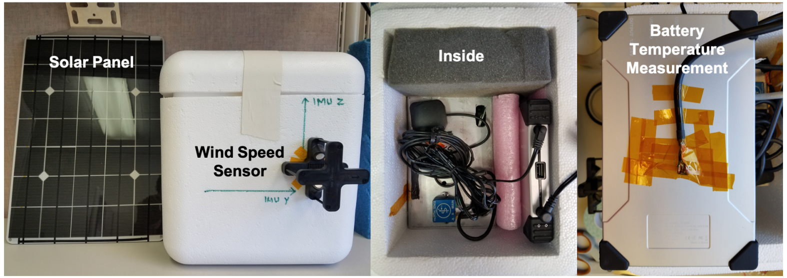




Coastally-reflected ocean infrasound



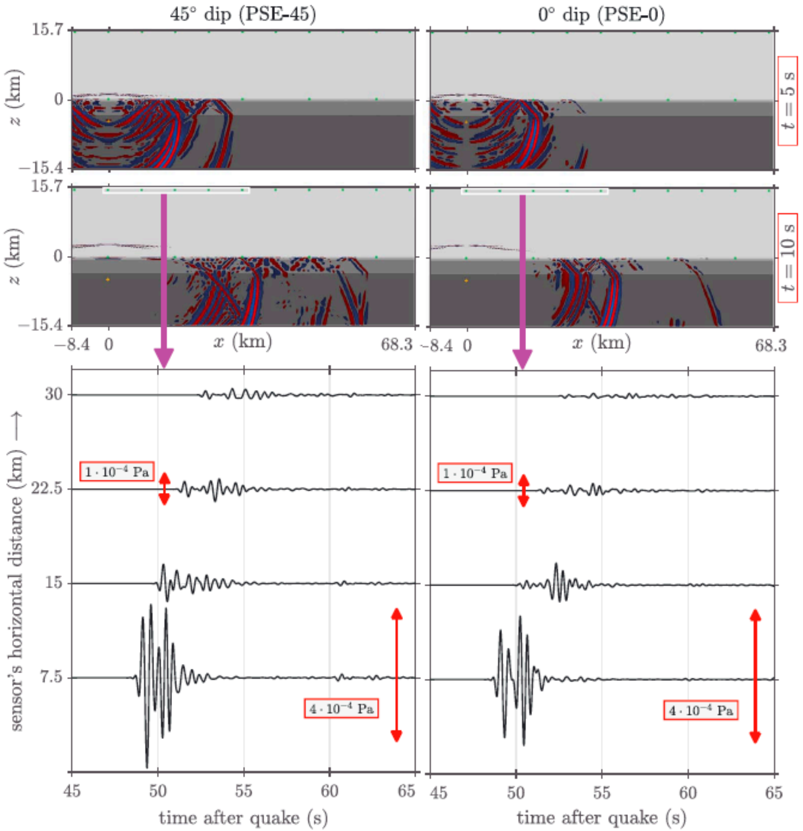
Visit poster#A33Q-2935
Wednesday Afternoon



- 2018 PMC Turbo Flight
- 2019 LDB Test Flight

Signal Modeling

- Signal modeling performed for Oklahoma using SPECFEM-DG (Martire et al., 2018 Brissaud et al., 2017)
- Arbitrary seismic source functions and atmospheric models can be incorporated
- Earthquakes with different dip angles found to produce different infrasound signatures
- Future efforts aimed at calibrating simulations on Earth-based data and mapping results to Venus



Martire et al., 2018

Balloon-Orbiter Complementarity

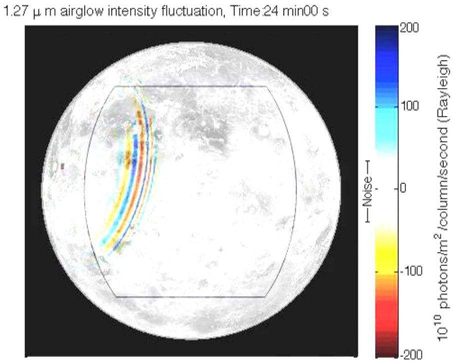
Infrasound Balloon

- Sensitive to smaller quakes (Magnitude > 3)
- Higher resolution, planetary coverage by drifting in winds
- Compatible with in-situ atmospheric investigations
- Geolocation is more challenging

Tibor Balint/JPL

Infrared Airglow Orbiter

- Planetary coverage – view of the whole disc
- Easier geolocation by analyzing successive frames
- Sensitive to larger quakes (Magnitude >5.3)
- Can provide communication relay and positioning for balloon



Komjathy et al., 2018

Strategic Areas for Future Work

- Demonstrate earthquake detection, location and characterization from **natural** earthquakes

- Establish detection limits for infrasound technique on Venus

- Develop methods for event discrimination and automated event identification – lots of airborne data to be collected

- Miniaturize sensor, develop “vector” infrasound concept

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jpl.nasa.gov